Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)




# A gripper for handling flat non-rigid materials.*

A. Karakerezis[a], Z. Doulgeri[b], V. Petridis[b]

[a] Dept. of Mech. Eng., A.M.A.R.C., University of Bristol, Queens Building, University Walk, BRISTOL. BS8 1TW U.K

[b]Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, 540 06 Thessaloniki, Greece

## Abstract

This paper deals with the concept, design, construction and experimental results of a gripper dedicated to the handling of flat non-rigid materials (NRMs). A consistent review in end-effector technology for NRMs has been made through this study. Based on a number of functional requirements a gripper is proposed with two moving finger-like attachment points and its performance is assessed experimentally. The final design study and construction of the gripper are presented. A set of experimental results of the gripper's performance and a discussion is provided.

## 1. INTRODUCTION.

Automated handling systems capable of dealing with **N**on **R**igid **M**aterials (**NRMs**) are very important for a number of manufacturing sectors like construction manufacturing, food-meat processing, aerospace industries, garment manufacturing, biomedical materials etc. NRMs (from sheet materials to dough-like compounds) present additional problems to rigid materials because they inherently deform significantly during handling; the system needs to react to these deformations which are mainly produced by the material's own weight, and the dynamic and gripping forces during handling. A large percentage of NRMs in manufacturing are flat like cloth, leather, paper-wall, composites etc., and this paper deals with this category of materials. An intensive literature survey on gripping systems for flat NRMs, showed that most of the proposed systems, are using a single arm robot equipped by a specific prototype end-effector to pick and place a piece of material from a stack. Hard automation devices like appropriate alignment and transfer devices are proposed to achieve further handling tasks [1-4].

The aim of the work described in this paper was to propose and construct a prototype gripper for a range of NRM handling tasks and specifically for picking, transferring, laying flat and folding, which have been identified as the most frequently encountered tasks in a number of industrial sectors and are currently performed manually. Their automation would greatly improve the productivity and cost effectiveness of these industries.

* This project was supported by the EC BRITE/EURAM program: NORMAH BE4259 "Research on Automatic Handling Techniques for Non Rigid Materials based on their Properties". The other partners of the project are: University of Bristol (AMARC), University of Parma.

## 2. LITERATURE REVIEW.

An intensive literature survey [24], focused on industrial grippers utilised in NRMs handling, showed that the proposed gripping systems can be grouped in four categories according to the type of gripping mechanism. **(a) Rollers** which are used mainly for pick and place operations and are based on the principle of rolling the material. In most of the cases the gripper is a cylinder which uses one of the following principles to grip the fabric: (i) *The electrostatic principle* [2], [10], [12], [14]. (ii) *Adhesive roll tapes.*[13]. (iii) *Oblique pins, needles* [2], [5-7], [9], and (iv) *Sucking* [5], [8]. **(b) Two Fingered** gripper mechanisms were developed, utilising mainly for operations of stacking and destacking. They usually employ auxiliary devices for the completion of the operation. For example in the process of ply separation (garment manufacturing), an air jet device is used to break up the bond between the plies. Some of these grippers use also vacuum for fabric attraction to the upper finger [2], [11], [13], [15], [16], [17]. Furthermore they are aided by sensors (infra-red, e.t.c.), either to detect the existence of the material between the fingers or to align the fingers with the edge before they are closed. **(c) Surface Grippers.** A group of surface grippers employ cushions implanted with pins or hollow adjustable needles to seize the fabric for pick and place operations. Hollow needles are used to blow compressed air through them for ply separation [5], [19]. Another group of surface grippers use the principles of either sucking [5], [8] with suckers arranged in a matrix for adapting to different shapes or freezing [5]. **(d) Adaptable grippers.** Adaptable Grippers are complex gripping systems which can grasp any irregular shaped flat material. There are only few gripping systems in this category. A multi-spiral gripper for example was developed strictly for leather industry. Four vacuum cups, each one connected on a spiral bar respectively, can move on them forming a plane [20]. A gripping mechanism similar to the previous one consists of four bars forming a trapezoid. A pneumatic sucker can move along each bar. The device allows to fix the suckers in the vertices of a trapezoid in 64 different ways [20].

For the prehension of the flat materials all the aforementioned gripping systems employ a number of gripping principles which can be classified in four categories: (a) *Insertion or intrusion* [2], [5-7], [9], [11], [19]. Pins, pin-hooks, needles or barbs are used to pierce plies. Such techniques are reliable for robust fabrics but they may create unrecoverable damages in the material, (b) *Clamping*, [2], [11], [13], [15], [16], [17]. Clamps or jaws are used. Gripping is stable but should be achieved from the edge. In case of stacks of materials (e.g. fabric) supplementary devices and sensors are necessary to ensure the ply separation and the gripping of one ply only, (c) *Pinch* [6], [11], [19]: Similar to clamps but the gripping technique is based on securing the top of the fabric. It is reliant on a smooth surface but has a tendency to crease the edges. It can then result in permanent deflections of the material (d) *Adhesion*, [1], [2], [5-10], [13], [15], [18], [20]. Some form of adhesion principles is used (e.g. electroadhesion, polymer adhesives, freezing, suction e.t.c.). Although the use of adhesives as a basic design concept present several advantages, including the simplicity of acquiring the material, the low probability of acquiring more than one ply at a time when the material is stacked and the wide applicability especially to all types of fabrics, the problems of material releasing mechanism, residual adhesive on the material, and adhesive tape breakage prevail.

An intensive literature review, showed that most of the grippers proposed use either pinches (42%) or needle-pins (42%) (figure 1). The preference in intrusion and adhesive principles is due to the simple grasping methods which they involve and the fact that the proposed grippers were specialised to one type of material for which the principle's disadvantages are not revealed. Intrusion as well as pinching principles may result in unrecoverable damages and distortions depending on the type of the handled material. Adhesion principles may present problems of material release, residual adhesive and they usually involve a bulky gripper. Grasping methods with these principles are basically simple and reliable. Clamping principles avoid material destruction, present the least distortion effects and they involve a non-bulky gripper but they usually require a more sophisticated grasping method to ensure reliability.

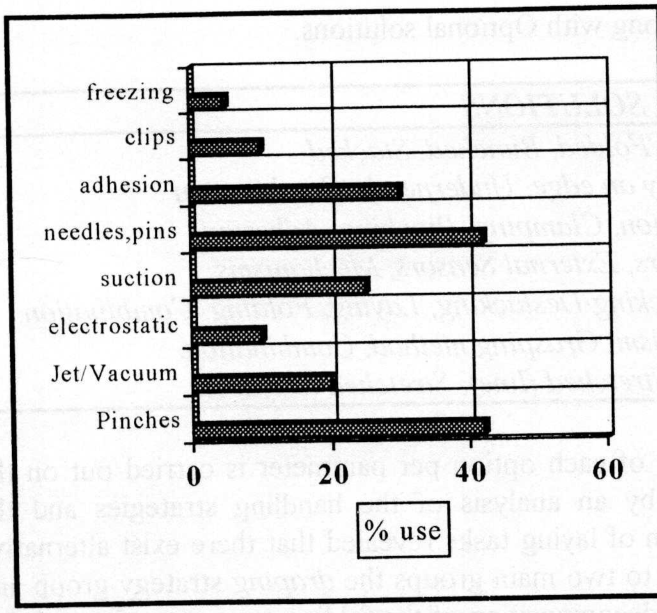


Figure 1. Use of gripping principles.

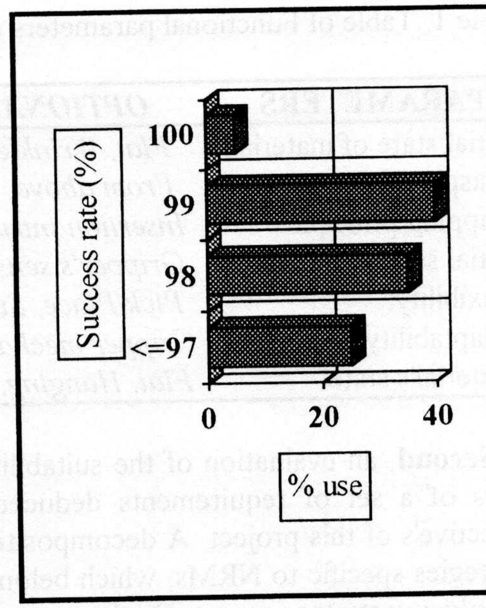


Figure 2. Percentage of success rate.

Considering the grippers' bulkiness we can distinguish three categories in decreasing degree of bulkiness on the basis of the state of the material when grasped. Specifically, the material may be flat as far as possible, rolled or hanged when it is grasped. The 31% of the reviewed grippers handle the material in a flat state, 42% handle the materials rolled and 20% hanged It is clear that the gripper mechanism determines this characteristic. Considering the reviewed grippers' complexity in terms of control, sensing and degrees of freedom, it was shown that 42% have high complexity and 47% are using conventional type of sensors (strain gauges, force-torque etc.) for the completion of the task. Regarding the grippers' flexibility in terms of the range of the handling tasks (e.g. grasping, laying, folding), grippers may be grouped in two main categories; those which were designed mainly for pick and place operations and those which have been used in other handling tasks like laying, two dimensional manipulation, folding etc. Most of the described grippers belong to the first category (79%). Regarding the grippers' adaptability to materials' sizes and shapes, literature survey showed that 73% had low adaptability and their sizes and shapes were, in most of the cases, fixed. Finally, figure 2 shows the success grasping rate of the reviewed grippers.

## 3. THE PROPOSED GRIPPING SYSTEM.

A flexible gripping system dedicated to gripping and handling of flat non rigid materials has been studied, designed, constructed and tested in Aristotle University of Thessaloniki. The objective of the engineering design in this work, was to produce a gripper with the least possible size, complexity and cost, and with the greatest degree of flexibility and adaptability necessary to achieve secure and non destructive grasping for a range of NRM types, sizes and shapes while meeting gripper requirements set by the handling tasks of picking, ,transferring, laying and folding which have been analysed in [22]. Three steps have been followed for the final selection of gripper design. **First,** an identification of significant functional parameters and the corresponding options which affect gripper design and are related to the performance of the operations (laying/flattening, folding) is made (Table 1), [22].

Table 1. Table of Functional parameters along with Optional solutions.

| PARAMETERS | *OPTIONAL SOLUTIONS* |
|---|---|
| Initial state of material: | *Flat, Wrinkled/Folded, Bunched, Stacked* |
| Grasping features: | *From above, By an edge, Underneath, Combination* |
| Gripping principle: | *Insertion/intrusion, Clamping, Pinching, Adhesion* |
| Initial secure grasp: | *Gripper's sensors, External Sensors, Mechanisms* |
| Flexibility: | *Pick/Place, Stacking/Destacking, Laying, Folding, Combination.* |
| Adaptability: | *Gripper mechanism, Grasping method, Combination.* |
| Material's state: | *Flat, Hanging, Stretched (line), Stretched (surface).* |

**Second**, an evaluation of the suitability of each option per parameter is carried out on the basis of a set of requirements deduced by an analysis of the handling strategies and the objective's of this project. A decomposition of laying tasks revealed that there exist alternative strategies specific to NRMs, which belong to two main groups the *draping* strategy group and the *placing* strategy group. Furthermore a decomposition of the folding strategies, showed that it did not impose additional requirements concerning the material state when grasped [22]. Main findings of this work revealed that most of the materials may be handled by a draping strategy in which case it is enough for the material to be grasped stretched along a line. Concerning the initial state of the material the stacked option is not taken into account since it has been already extensively researched. In addition the aim to deal with both flat and wrinkled/folded states means that the gripper should be able to stretch the material between the gripping points until is taut. The objective not to distract or deform any material within the range of types considered, specifies the clamping option as the only solution for the gripping principle. Given the two gripping points and the clamping gripping principle the grasping features should in consequence be from an edge. The initial secure grasping of the material is established by the gripper design and the grasping method and is discussed in the following section. The following conclusions concerning the gripper can be summarised: (a) the gripper should have two gripping points, (b) the minimum and maximum distance between the gripping points will determine the range of sizes which can be handled, (c) the ability of the gripper to stretch the material along a line and adapt to different edge sizes is necessary. Thus, a mechanism to automatically move apart the gripping points is necessary, (d) the gripping system would be capable to handle all the considered material types apart from the sticky and the highly non convex ones which would not be stacked but could be flat or wrinkled/folded in their initial state.

**Third**, a number of alternative design solutions have been produced complied with the above conclusions [24]. The final selection of the gripping system for construction was based on parameters concerning accuracy, construction simplicity, availability of the off self part components and the time and cost constraints of the project.

## 4. IMPLEMENTATION.

For the implementation of the final solution an appraisal of alternative construction solutions has been made based on criteria like system resolution, system repeatability, weight, and performance speed [21]. The final gripping system design solution is shown in figure 3. It is comprised by two sliders which can move along a stainless carriageway seated on an aluminium frame. A lead screw seated again on the frame and supported by bearings, is connected with a stepper motor and guides through essence the two sliders. The gripper blocks which are mounted on the sliders are an on-off two fingered pneumatic grippers and are shown in figure 4. The maximum distance between the blocks is equal to 0.5 m which is the average length of the pieces encountered in the NRM industry .

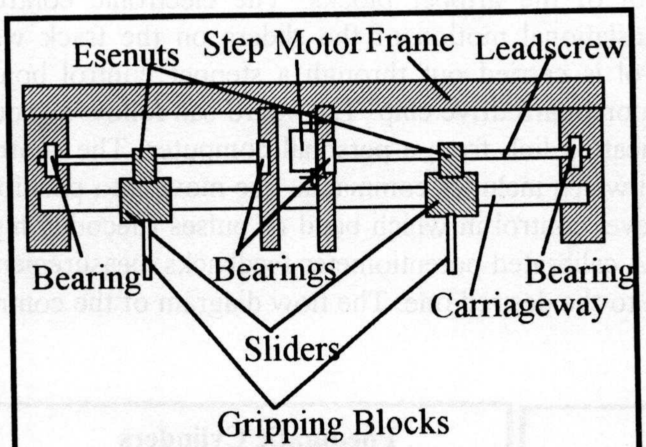


Figure 3. Final design solution based on carriageway.

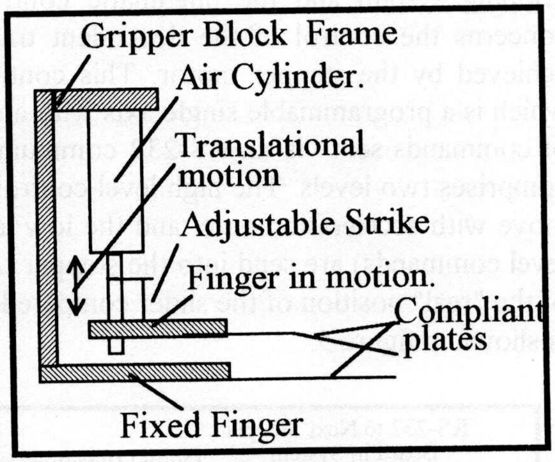


Figure 4. Two fingered gripping mechanism.

One finger is mounted fixed on the frame and the other one, which is mounted on a pneumatic cylinder, can move translational up and down. The fingers are perpendicular to the gripper block to facilitate the robot trajectory during scooping. The gripper has an adjustable on-off strike and the fingers are able to carry compliant plates. The maximum operating pressure is 7 Kgf/cm$^2$ and the control is on-off. The pair of compliant attachment plates is mounted on the gripper rigid jaws. The plate attached to the moving jaw is angled in a predefined way. The fixed plate is provided by a sharpen edge nail to reduce the possibility to push away the material and thus facilitate insertion underneath it. Material slippage at the close jaw operation is avoided because the plate is fixed. The compliance of the plates depends on the material used for their construction and their thickness. The plate material was chosen to be hard and elastic. Plates of different compliance may be used for successful grasping . The designed gripper allows easy change of attachment plates. The gripping force exerted on the material when grasped between the attachment plates is a function of the gripper jaw displacement after the initial contact of the attachment plates and a number of attachment plate parameters. The displacement may be altered either by adjusting the gripper jaw displacement or by changing the plate angle given that at the maximum gripper opening the requirements for the minimum necessary initial gap between the attachment plates are respected.

A *grasping method* was developed to ensure successful grasping while keeping the two finger gripper blocks simple. Specifically, grasping is achieved by the following strategy: the robot moves its end down to the working table's surface to a position near the gripping line and to an orientation which results in the gripper blocks being positioned in a line parallel to the gripping line. It then moves towards the gripping line by keeping contact with the table and with the fingers of the gripper blocks open until the lower fingers are inserted underneath the material. Sensing will be used to secure the existence of the material between the jaws. A jaw close operation will terminate the grasping phase. The initial contact of the lower jaws with the table's surface and their constrained move on the table's surface will be realised with the use of a wrist force/torque sensor. As a result, fingers should have a degree of compliance, their thickness should be small, and their configuration should ensure firm grasping.

The Control of the Gripping System is consisted of two parts, the electronic control of the gripping system and the pneumatic control of the gripper blocks. The electronic control, concerns the control of the dependent translational motion of the sliders on the track way achieved by the stepper motor. This control is carried out through a stepper control board which is a programmable single axis with an on board drive chip. The board can follow a group of commands sent via an RS-232 communication link from a personal computer. The control comprises two levels. The high level control which includes commands like move into position, move with acceleration e.t.c. and the low level control in which baud of pulses (decoded high level commands) are send into the stepper. A calibrated potentiometer feedbacks measurements of the "real" position of the slider compared to the desired one. The flow diagram of the control is shown in figure 5.

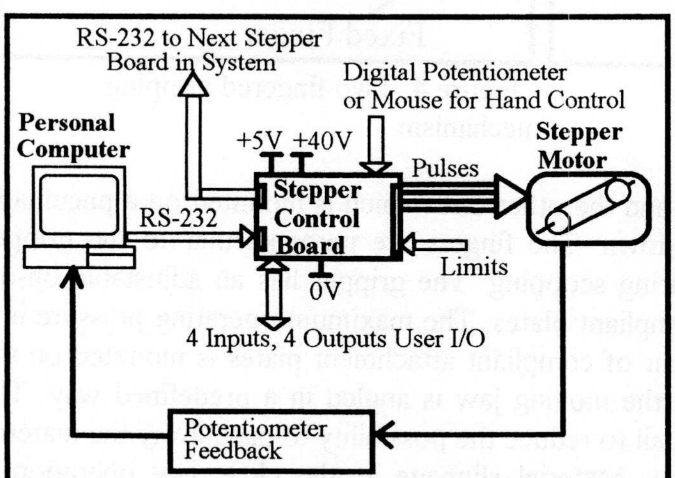


Figure 5. The control flow diagram

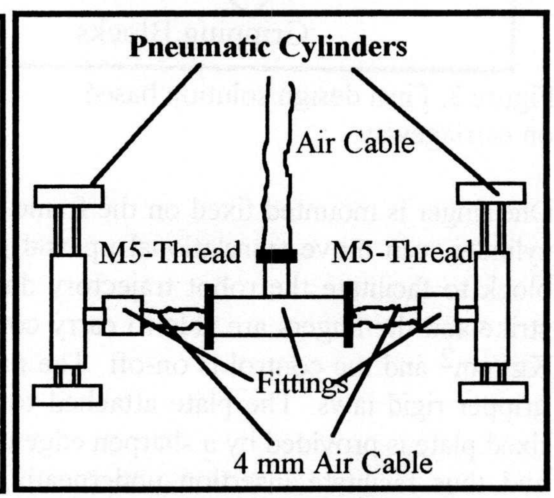


Figure 6. Pneumatic Flow Diagram.

The pneumatic control of the gripper blocks is a simple on-off operation dependent on the provision of the pressurised air. Two pneumatic circuits are employed for the on-off control operation of the gripper. The ON action activates the first circuit which actually closes the fingers and the OFF action directs the second circuit which opens the fingers. The two circuits have the same structure design shown in figure 6.

Regarding sensing requirements of the proposed gripper three different sensors have been employed for the successful operation of the gripper. An external vision system is used for the establishment of the existence of the material between the compliant plates. A robot wrist force/torque sensor is used to establish and keep the contact of the gripper to the working table. Finally a potentiometer is used for the compensation of the position of the gripper blocks. The following photographs portray the gripping system in "action".

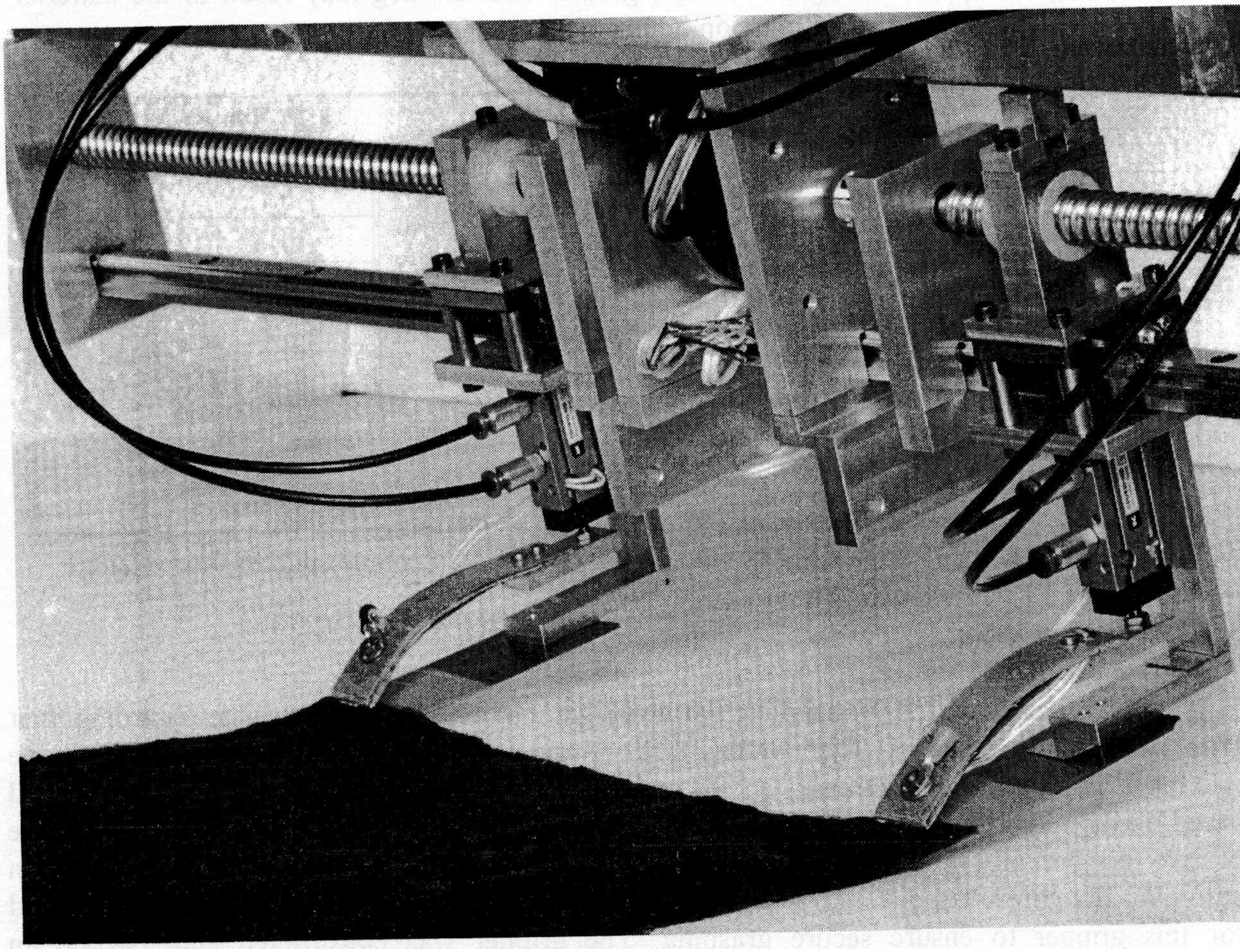

Figure 7. The gripping system in "action".

## 5. EXPERIMENTS.

A number of experiments have been carried out to assess the gripper performance and establish the importance and the required values for a number of grasping method parameters for secure grasping as a function of the material type [23]. Specifically, four experimental parameters have been identified as crucial for grasping experiments: the approach velocity, the approach angle, the approach acceleration, and the initial distance. Experimental set-up and parameters are shown in figure 8. The gripper was attached to a PUMA 760 robot and the table surface was of low roughness. The manipulator acceleration could not be specified explicitly in this set up. It was decided to use a small initial distance (1mm) so that the manipulator is at the acceleration phase (the final velocity is not yet achieved) when scooping starts. The approach velocity was varied from 0.0065 m/sec to 0.05 m/sec with a step of 0.0015 m/sec. The approach angle was varied from 10 deg to 40 deg with a step of 10 deg. Finally, the initial distance varied from 1 mm to 100 mm with step of 1 mm.

The following findings can be summarised, (a) It was found that material is grasped securely, irrespective of its type if a high acceleration is adopted (small distance and high velocity). Material types include a big range of materials from low to high stiffness (silk, cotton, denim, paper, plastic, composites etc.), (b) Regarding the approach angle, it was found that increasing the approach angle to values greater than 20 deg may result in the material being pushed away from its initial position before grasped (figure 9).

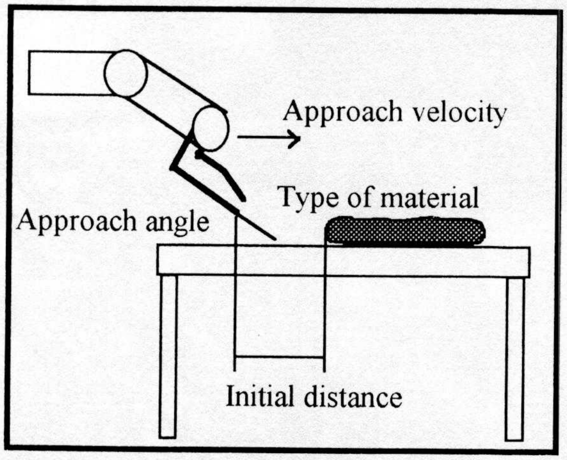


Figure 8. Experimental set up and parameters.

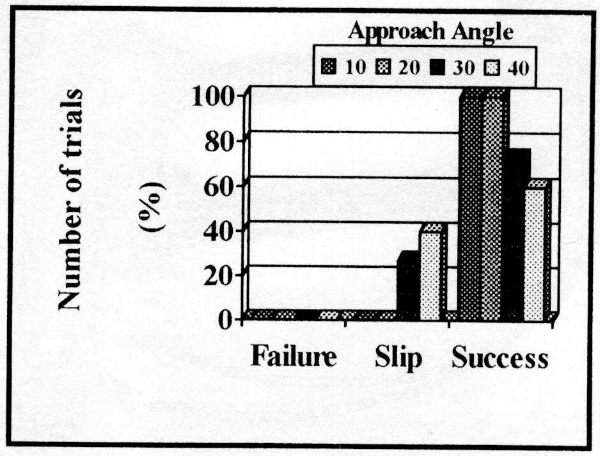


Figure 9. Percentage success rate vs angle

## 5. CONCLUSIONS.

A gripper was proposed for handling flat non-rigid materials of a broad range regarding their properties, sizes and shapes. The handling tasks considered were laying flat, and folding as the two most frequently identified tasks across various industrial sectors. The gripper was designed based on the requirements set by the analysis of the handling tasks. It is based on the principle of two gripper blocks equipped with two compliant fingers, which may be placed in an automatically controlled distance along a bar. A sensor based grasping method was developed for this gripper to ensure secure grasping. The gripper was constructed and used in an experimental set up for a large number of experiments for all material types. It was established that: (a) the attachment plate should be sharp and thin, as a result a nail was mounted to one of the fingers) (b) The approach angle of the gripper does not affect the gripping if it is less than 20 degrees. (c) A high approach acceleration before the insertion of the gripper underneath the material secure the gripping for all types.

***Acknowledgements.***
The authors of this paper would like to thank the EC BRIGHT/EURAM Commission for their support and the A.M.A.R.C., University of Bristol, for their invaluable help during the construction of the gripper.

## REFERENCES.

**1.** T.G. Clapp, D.R. Buchanan, Limp materials reserach of North Caroline State University, Dept of textile eng. chemistry.

**2.** P.M. Taylor and G.E. Taylor, Progress towards automated garment manufacture, NATO ASI Series, Sensory Robotics for Handling Limp Materilas, F64:97-109, (1990).

R.B. Kelley, Research on the automated handling of garments for pressing, Int. Conf. on Advanced Robotics 7803-0078/91:796-801 (1991).
P.N. Brett, A.P. Shacklock, and K. Khodabandehloo, Research towards generalised robotic systems for handling non-rigid products, Int. Conf. on Advanced Robotics 7803-0078/91, IEEE: 1530-1533.
G. Schulz, Grippers for flexible textiles, Int. Conf. on Advanced Robotics (fifth) 7803-0078/91:759-764,(1991).
M. Sarhadi, Robotic handling and lay-up of advanced composite materials an overview, NATO ASI Series, Sensory Robotics for handling of limp materials, F64:34-49, (1990).
J.K. Parker, R. Dubey, F.W. Paul and R.J. Becker, Robotic fabric handling for automatic garment manufacturing, Journal of Eng. for Industry, 105:21-26, (1983).
S.D.H. Jarvis, K. Wilcox, X.Q. Chen, R. McCarthy and M. Sarhadi, Design of a handling device for composite ply lay-up automation, Int. Conf. on Advanced Robotics 7803-0078/91 IEEE:790-795.
M. Sarhadi, P.R. Nicholson and J.E. Simmons, Advances in gripper technology for apparel manufacturing, IMechE C372/86:47-53 (1986).
G.J. Monkman and P.M. Taylor, Electrostatic grippers, principles and practice, Proc of the 18th ISIR , Lausanne.
A.A.Brotherton and J.D. Tyler, Clupicker performance and flexible apparel automatic, Hoolings Apparel Industry, 3 (2) : 15-34.
E. Torgeson and F.W.Paul, Vision-guided robotic fabric manipulation for apparel manufacturing, IEEE Control System Magazine 14-20.
P.M. Taylor and S.G. Koudis, Automated handling of fabrics, Sci. Prog. Oxf. 71:351-363 (1987).
Taylor, Monkman, Taylor, Electrostatic grippers for fabric handling.
D.R. Kemp, G.E. Taylor, P.M. Taylor, and A. Pugh, A sensory gripper for handling textiles, Robot Grippers by Pham and Heginbotham (eds).
E. Ono, H. Ichijou, N. Aisaka, Robot hand for handling cloth, Int. Conf on Advenced Robotics 7863-0078/91:769-774.
H. Okabe. E. Ono, H. Akami, K. Sasaki, On the sensing of cloths by sensors implanted in robot fingers, Bulletin of Institute. by Polymers and Textile, 147:23-29, (1985).
J.C. Colson, Robotic tool for the application of non-rigid adhesive-backed parts, IBM Technical Disclosure Bulletin 26 No 9: 4678-4679 (1984).
Polytex cloth pick up device, Type NG. Polytex AG, Switzerland.
M. Betemps, Herve-Tanneguy, Redarce Jutard, Development of a multi-spiral gripper for leather industry, Int. Conf. on Advanced Robotics, 7803-0078/91:1726-1729 (1991).
A.Karakerezis, Alternative construction designs for the gripping system of two attachement points, Internal report, NORMAH BE 4259, AUTH, 1993,
A. Koutsou, A. Karakerezis, Decomposition of laying and flattening tasks, Internal report, NORMAH BE4259, AUTH, 1992.
A.Karakerezis, Performance requirements and experimental tests for the gripping system of two attachment points, Internal Report, NORMAH BE4259, AUTH, 1993.
A. Karakerezis, A literature review in end effector technology for grasping NRMs. Evaluation and Conception of gripping systems, Internal Report, NORMAH BE 4259, AUTH, 1992.